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SOME PROBLEMS OF THE BOULDER CANYON-COLORADO RIVER DEVELOPMENT

By JOHN L. BACON, Chairman, California-Colorado River Commission

June 15, 1931.

The Colorado River, like all streams flowing through a semiarid country, has periods of extreme high and low flow. These periods are of annual occurrence and are fairly uniform both as to amount and time. During the periods of high water a serious flood condition exists along the lower reaches of the river that at times is an acute menace. During the low-water periods there is sometimes an absolute water shortage, with not enough water to supply the existing demand for irrigation and domestic purposes. This low-water flow naturally limits the demand that may be satisfied from the river, and the limit has been reached.

The variation in the flow of the Colorado is very great. Many seasons the flood has reached a flow in excess of 200,000 cubic feet per second, and during the dry season this flow has dropped below 2,000 second-feet. About 5,000 or 6,000 second-feet of flow is required to satisfy the demand at and below Yuma.

One condition exists that is peculiar to this river—the largest single area using water lies entirely below sea level.

The Imperial Irrigation District, comprising over half a million acres, lies in what at one time was the end of the Gulf of California. Silt brought down by the Colorado formed a delta across this arm of the sea, extending across the entire width of the valley, from the present bank of the river in Arizona to the high hills along the western side of the valley in California. Silt formed the valley and now threatens to destroy it by the continual building up of the delta and the forcing of the river into new channels that have a constantly increasing tendency to flow back into the valley below.

The amount of silt coming down the river every year is about equal to the total amount of excavation the Americans dug out of the Panama Canal. To prevent the mouth of the river being diverted down the northern slope of the delta and back into the Imperial Valley by the ever-increasing deposit of silt, the Imperial Irrigation District has been compelled to maintain an ever-lengthening system of dikes or levees along the lower reaches of the river in Mexico. To-day there are about 75 miles of these levees in use, and some 21 miles in addition have been built, which have either been destroyed by the river or abandoned on account of improper location.

The elevation of the delta, where the river is flowing, is some 50 to 75 feet above sea level, while the Salton Sea, which fills the bottom of the bowl forming the Imperial Valley, has a surface elevation of about 250 feet below sea level.

In addition to the natural difficulties encountered on the Colorado there are many and grave political complications. The Colorado flows through the States of Arizona, Nevada, New Mexico, Utah, Colorado, and Wyoming and borders on California for some 250 miles. From the international border line the river flows through Mexico before entering the Gulf of California, and considerable water is used there for irrigation. There are vast areas in each of these States, as well as Mexico, whose every interest is entirely dependent upon the water obtained from the Colorado. Each of these areas is jealous of development in other areas and will go to almost any length to protect real or fancied opportunities of future development.

We have, then, not only an interstate but an international complication. We have no treaty with Mexico regarding allocation or use of Colorado River water. There is no agreement between the States making a definite allocation of use between individual States, although the so-called Colorado River compact does make an allocation of use between two groups of States known as the upper and lower basin States. Roughly, the States of Arizona, California, and Nevada comprise the lower basin and the States of Utah, Colorado, Wyoming, and New Mexico the upper basin, although portions of some of the States overlap both basins.

Problems on the Colorado were really brought to an acute head by conditions in the Imperial Valley. When irrigation and settlement first started in 1902 little attention was paid to the delta conditions and water was diverted through an old stream bed running along close to the top of the delta, starting at about the intersection of the Colorado with the international boundary line, looping down through Mexico, and crossing back into the United States about 40 miles west of the Colorado.

The promoters had a concession from the Mexican Government under the terms of which Mexican lands were to have half of the water flowing in the canal at any time.

Some 13 years ago the people of Imperial Valley, realizing that serious conditions were developing and that the problems were becoming too serious for them to handle, went to Congress and asked for aid. The first step was a bill to construct what was known as an All-American Canal to connect the Colorado River with the Imperial Valley and relieve the valley of the ever-increasing international complications that were developing. This bill was not passed, but it did, along with other bills which succeeded it, rouse sufficient interest so that Congress in 1920 authorized a thorough investigation and report of the conditions on the Colorado with the view of determining some possible solution of the ever-increasing difficulties.

The result of the above investigation was a report rendered in 1920, known as the Fall-Davis report, recommending the construction of the Boulder Dam, afterward named the Hoover Dam. As set forth in the report, the object of such a dam was to provide sufficient storage to impound an entire year's run-off of the Colorado, and then feed this stored water downstream for use when needed, thus utilizing the flood waters that had been running to waste and making them available when most needed during the dry periods. It also recommended that the waters from the dam be passed through a power house and that the energy thus generated be sold, it being believed that the income from this source would be sufficient to repay the entire cost of the investment. An all-American canal was also recommended to carry water from the river to the Imperial Valley and replace the present canal in Mexico.

This was the solution offered by the Government engineers, and so well was it worked out that, though numerous other investigations have since been made and many other reports rendered, the development as it is going ahead to-day practically follows the recommendations made in the Fall-Davis report.

Briefly, the situation might be summed up in this way: The conditions were laid before the Reclamation Department and after careful investigation the answer came back—build Boulder Dam. The object to be attained was to control the river, store the floods, and feed down the water when needed, and in the process of feeding down the water run it through a power house and let the drop of the water pay for the cost of control by selling the power thus generated.

After numerous failures to obtain favorable action by Congress, the so-called Swing-Johnson bill was passed, authorizing the construction of a dam in the Colorado River at Black or Boulder Canyon, the construction of a power plant below the dam, and the building of the All-American Canal. This bill passed December, 1928, and the first appropriation was authorized in the deficiency appropriation bill signed by President Hoover July 3, 1930.

These are only a few of the high points among the events leading up to the start of the Hoover Dam.

The financing of the project and the actual construction present many interesting and big problems. Before work could start the Secretary of the Interior was compelled by the terms of the act to have contracts for the disposal of the power that would guarantee to the Government the full repayment of all money invested plus interest at 4 per cent. This was accomplished. An immense river must be diverted from its bed and carried around the actual site of the dam. The structure will be the largest block of concrete ever cast, The mere financing of the construction work by the contractors is no mean proposition.

The Boulder Dam, as it has been popularly known, or the Hoover Dam, as it is now and will hereafter be officially known, is to be an arch gravity section concrete dam in the Colorado River about 250 miles upstream from the point where the Colorado crosses the international boundary line between California and Mexico. The location is about 150 miles below the limits of the Grand Canyon National Park. These distances are measured along the river and would be slightly shorter if taken in a direct line. It is about 30 miles southeast of Las Vegas, Nevada, the nearest city. The river at this point runs through a deep, narrow gorge over 1,000 feet deep, that almost looks as though nature had provided it for this particular purpose.

The dam will be over 700 feet high from bedrock to top, will impound over 30,000,000 acre-feet of water, creating the largest artificial body of water in existence behind one dam, and will make an artificial lake over 100 miles long.

The financing of the project has proven an extremely interesting problem. The act provided for considerable latitude. The Government could either lease the right to use the falling water, it could build a power plant and lease the plant or units of the plant, or it could build and operate the plant and sell the power thus generated at the switchboard.

A sort of combination of these methods was finally worked out, and under the final contracts the Government is to build the building housing the power plant and control the water up to the control valves, the lessees pay for the generating machinery and operate it, and pay the Government for the use of the falling water, the rate of payment to be governed and measured by the amount of water required to generate a kilowatt of electrical energy at the switchboard at the plant. The rate to be paid is 1.63 mills per kilowatt-hour for primary or firm power and 0.5 mill for secondary or what might be termed "spill" power. There will be other items of income, but the income from power alone during the 50-year amortization period of the dam will yield an average of over $7,000,000 per year. Of this income Arizona and Nevada will *each* receive over $600,000 annually, without the expenditure of anything on their part.

During the 50 years in which the dam and all expenditures must be paid for, with interest at 4 per cent, the income will be sufficient to pay all capital costs, operate and maintain the works, provide for depreciation, pay the interest, pay the amounts given above to Nevada and Arizona, and in addition provide a fund that may be used for general development of the Colorado of over $66,500,000. The initial cost to the Government, including $11,554,000 to be charged for interest during construction period, is estimated at $121,000,000. In addition the All-American Canal, estimated to cost about $32,000,000, will be a separate financial set-up.

Perhaps the most novel feature of the construction of this huge dam is the method to be used to carry off the heat generated by the chemical combinations and reactions of the setting cement. Very little attention is ordinarily paid to this in common practice, as the mass of the setting concrete is generally small enough to permit the radiation of the heat generated without any difficulty; but in the case of the Hoover Dam, where the mass is over 600 feet thick in some places, the carrying off of this heat becomes a real problem. A method or refrigeration, or artificial cooling, has been worked out to take care of the unusual conditions brought about by the great mass of the concrete and by the rapidity of pouring. (It is expected to pour concrete at the rate of 3,000 yards per day.) Shrinkage takes place in the mass until the heat generated by setting has been dissipated.

The following data have been furnished by the Denver office of the Reclamation Department:

The object to be obtained by artificially cooling the concrete during the setting period is to dissipate its setting heat in a relatively short period of time, so that the resultant shrinkage of the mass will take place before it is necessary to pressure grout the construction joints and impound water behind the dam. The chemical action in setting concrete develops a large amount of heat, which heat is rapidly dissipated by radiation when in masses of small dimensions. On the other hand, this heat radiation from large masses is relatively very slow and varies as the square of the dimensions of the mass. On this basis the degree of cooling that would naturally take place by radiation from a mass 50 feet in thickness (a representative dimension for concrete arch dams of ordinary magnitude) in one years' time would require a century if the structure were 500 feet thick, which may be taken as the average thickness of the Hoover Dam. Shrinkage in the mass will continue until the setting heat is dissipated. To correct for this and to make the structure monolithic and water-tight, the contraction joints provided for this purpose will be filled with cement grout under pressure after the cement has cooled. The artificial cooling is therefore required in order to permit the completion and use of the dam within a permissible period of time. The rated capacity of the cooling plant is 600 tons per day.

The circulating pipes in the concrete are to be spaced 10 feet apart vertically and about 11½ feet apart horizontally. The approximate basis for estimating the amount of heat to be removed is 50,000 to 60,000 B. t. u. per cubic yard of concrete as an average condition. Data of record relative to the thermal properties of concrete are comparatively meager and, in some instances, apparently erroneous. A suitable series of experiments will be conducted to establish these properties for the specific materials to be used before concrete placing is begun.

The injurious effects to be anticipated if no provision were made for artificial cooling are the cracking of the concrete and the opening up of the construction joints due to shrinkage from cooling after the structure is completed and put in use. Such cracks and open construction joints would invite leakage and would disarrange the distribution of stresses between the arch and cantilever elements, which would result in concentrated stresses much higher than calculated in the design of the dam due to the structure not being able to act as a monolith.

The turning of the river to permit the unwatering of the actual dam site is no mean undertaking. To do this, four tunnels are to be driven, two on the Nevada side and two on the Arizona side of the river. The bottom elevation of these tunnels will be about the low-water flow line of the river. Each tunnel will be about 50 feet in diameter when finished, and the combined capacities of all four will be about sufficient to take care of the average flow of the Mississippi River at St. Louis. The capacity will be 200,000 cubic feet of water per second. When these tunnels are completed, cofferdams of rock-fill construction, faced upstream with steel-pile cut-off walls, will be constructed, one just below the upstream intakes and one just above the downstream discharge ends of the tunnels. These cut-off dams will raise the water at the upstream end and divert the flow of the river through the completed tunnels, and the downstream dam will prevent the water from backing up and flooding the site.

After the main dam is completed, all four of the tunnels will be plugged at the upstream ends. One tunnel on each side of the river will be used for a spillway by connecting with a slanting shaft having its upper end at the water surface of filled reservoir. The other two tunnels will be plugged at both ends and will be utilized as pressure tunnels to connect with the control gates in the inlet towers.

SOME FIGURES ON THE HOOVER DAM

In order to gain some conception of the magnitude of this great project it does not seem out of place to list some of the items that will enter into it.

Tunnels.—Combined length, 3.1 miles; cubic yards of excavation in rock, 1,900,000.

Cofferdams.—1,200,000 cubic yards of rock and earth fill.

Reinforcing steel bars and rails.—35,500,000 pounds.

Concrete.—4,400,000 cubic yards.

Miscellaneous items.—Small metal pipe and fittings, 1,900,000 pounds; structural steel, 10,600,000 pounds; large metal conduits, 32,500,000 pounds; metal work, gates, hoists, etc., 20,000,000 pounds.

Time to build.—About six or seven years.

It is estimated that it will require about 350 carloads of material daily to keep up with the demand for supplies during the construction period.

Even the seemingly simple element of elevator service looms rather large when it is realized that enough workmen to man a good-sized manufacturing plant must be handled in and out of a canyon over a thousand feet deep.

This dam will be the Government's answer to a series of vexing problems that have developed in connection with the river and will, as has been aptly said, "Convert a natural menace into a national resource" and will mark one more milepost in man's struggle against nature.

SOUNDING-BALLOON OBSERVATIONS MADE AT BROKEN ARROW, OKLA., DURING THE INTERNATIONAL MONTH, DECEMBER, 1929

By L. T. Samuels

[Weather Bureau, Washington, D. C., July, 1931]

In cooperation with the International Commission for the Exploration of the Upper Atmosphere the Weather Bureau conducted a series of sounding-balloon observations at the Broken Arrow[1] (Okla.) aerological station during the international month, December, 1929. The instruments used were of the Fergusson type. The balloons were made of seamless rubber and weighed between 575 and 1,238 grams. They were spherical in shape, between 75 and 100 centimeters diameter, and were inflated to between 137 and 158 centimeters diameter. This gave a free lift of approximately 500 grams and an ascensional rate of about 238 meters per minute.

The balloons were released daily about one hour before sunset so as to eliminate, so far as possible, the effects of insolation on the meteorograph and still make possible the use of theodolites to follow the balloons. On the 17th, 18th, and 19th (international days) additional balloons were released shortly after sunrise. There were 34 observations made, and 26 (76 per cent) of the instruments were returned. One of the latter had the record sheet removed and another had a faulty pressure record. Of the eight instruments not returned, three were followed with two theodolites to the following heights, viz, 13,175 meters on the 2d, 7,420 meters on the 26th, and 17,590 meters on the 30th. Wind velocities and directions were determined to those elevations.

The balloons were followed with two theodolites whenever possible, and in nine cases these continued for 60 minutes or more, the longest run being 90 minutes on the 25th.

[1] Latitude 36° 02′ N., longitude 95° 49′ W.